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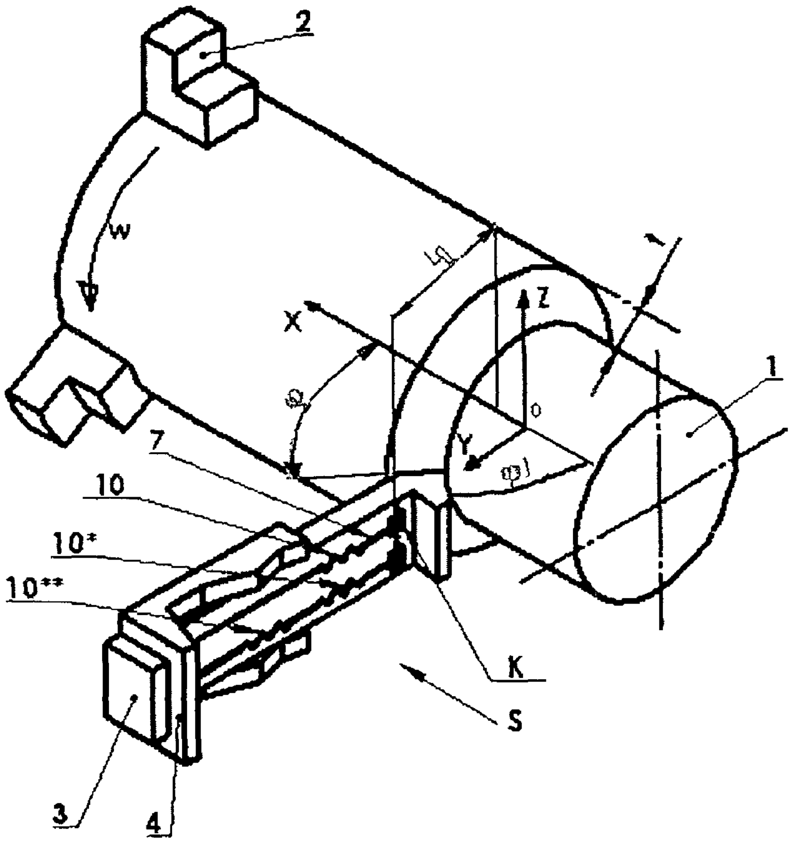
[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR VIBRATING CUTTING TOOL



(57) Abstract: A vibrating cutting tool (3) contains a fixed working part (5), a cover (6) connected to said working part, an oscillation loop (7), a movable working tool (8) and a set of elastic elements (10, 10* and 10**) which connects said movable tool with the fixed working part.

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Published:
— *with international search report*
— *with amended claims and statement*

METHOD AND APPARATUS FOR VIBRATING CUTTING TOOL

BACKGROUND OF THE INVENTION

The present invention relates to machine industry, in particularly to metal machining by cutting tools with one or more cutting edges.

The proposed vibration cutting method is intended for chips breakage when machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials by proposed vibrating cutting tool. The vibrating cutting tool performs feed motion and oscillation motion in feed direction due to components of cutting resistance forces thus increasing cutting speed without additional power supply and special devices. At the same time a cutting plate durability and machining accuracy are increased.

Known are vibration cutting methods containing mechanical, electromechanical, hydraulic, magnetostrictive and other drivers for producing oscillating movement of various cutting tools. But when machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials these drivers contain various oscillation generators with additional devices and equipment.

Known is US Patent No. 5,113,728 "Method and apparatus for forming intermittent chips when machining a rotating workpiece", issued on May 19, 1992 (Patent Application No. 596041 filed on October 11, 1990). The main disadvantage of this Patent as well as other technical solutions aimed to form intermittent chips when machining workpieces is that they need cutting tool connection to a additional device which contains a separate driver and oscillation generator.

Known are cutting tools which contain removable cutting plates with hitches, horns and grooves arranged along cutting plate perimeter.

But when machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials all these static solutions are non effective and upon increasing cutting speed the machining becomes impossible due to fast wear and breaks of cutting plate.

Known is the Patent of Japan No. 08300207 for "Vibrating blade" issued on Nov.19, 1996 (Patient Application No. 07108670 filed on May 2, 1995). The main disadvantage of this Patent as well as other technical solutions for machining hardly machined steels and alloys is that they need cutting tool connection with additional device which contains separate driver and which causes an increased power consumption.

To disadvantages of the known designs has to be referred also a rigid drive connection between cutting tool and oscillation generator of additional devices. This is followed by cutting speed, durability and machining accuracy reduction.

The proposed invention is aimed to create vibrating cutting method that enables to form intermittent chips by proposed vibrating cutting tool which performs feed motion and oscillating motion in feed direction due to cutting resistance forces and elastic elements of cutting tool oscillation loop and to increase cutting speed without additional power supply for cutting tool oscillating movement, to increase cutting plate durability, to provide machining accuracy and surface asperity value.

SUMMARY OF THE INVENTION

For this purpose to be attained, it is proposed a vibrating cutting method when machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials applied to lathe with cutting tool that has forward path feed movement. The method contains the following stages:

- workpiece rotation around rotation axis;
- cutting tool adjustment into strictly determined positions on its forward path feed movement according to rotating workpiece angle

positions during cutting process so that:

- under impact of cutting resistance forces the cutting tool nose position has sinusoidal shape with different oscillation amplitude (A) and micro asperity height (h);
- oscillation amplitude of cutting tool and micro asperity height may be regulated;
- at phase angle τ values equal to zero, (π) and (2π) the cutting tool edges position under angle oscillations coincides with that of even cutting, the cutting layer section and micro asperity height for indicated phase angle values are equal while the cutting tool nose paths on two consecutive revolutions provide intermittent chips,
- at phase angle τ equal to π divided two times ($\pi/2$) the cutting tool nose paths are located on the maximum distance from each other, micro asperity height (h_{max}) is maximal, cutting tool nose oscillation amplitude fulfills condition A=0.5S, where S is feed value, thus intermittent chips are provided;
- at phase angle τ equal to three π divided two times ($3\pi/2$) the cutting tool nose paths touch each other, the cutting layer section is minimal, the cutting layer depth changes to zero and chips fracture occurs;
- regulation of said cutting tool nose oscillation amplitude (A) by elastic elements of different rigidity that are included into vibrating cutting tool oscillation loop.

The proposed cutting tool contains a fixed working part; a cover connected to the said working part; an oscillation loop which includes movable working cutting tool part, one or several replaceable cutting plates, secured on the said front working part; a set of elastic elements which connect said movable working cutting tool part with the basis of the said fixed cutting tool working part; said oscillation loop oscillation shaft secured between the basis of the said fixed cutting tool part and said cover; while said movable working part with secured on it said replaceable cutting plate is mounted on said shaft with possibility of rotation due to cutting forces components.

BRIEF DESCRIPTION OF THE DRAWINGS

Peculiarities and advantages of the proposed invention will become more evident on consideration of the preferable invention realization sample which is given exclusively for example with references on the attached drawings, wherein:

Fig.1 schematically shows vibration cutting tool with angle oscillations when performing turning machining operation.

Fig.2 schematically shows a machining surface and cutting layer sections when performing turning machining operation with cutting tool angle oscillations.

Fig.3 schematically shows cutting tool nose paths in the XOY plate;

Fig.4 schematically shows vibrating cutting tool when performing turning machining operation, top view;

Fig.5 –section B-B, see Fig.4;

Fig.6 schematically shows vibrating cutting tool when performing cutting operation – top view;

Fig.7 schematically shows vibrating cutting tool when performing cutting operation – side view.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The proposed vibration cutting method for machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials (Fig.1 to Fig.3) is schematically shown at example of turning machining operation performed on lathe and comprises the following stages:

- workpiece rotation around rotation axis;
- cutting tool adjustment into strictly determined positions on its forward pathway movement according to rotating workpiece angle positions when performing cutting process;
- regulation of said cutting tool nose oscillation amplitude (A) is performed by elastic elements of different rigidity that are included into vibrating cutting tool oscillation loop. Thus when adjusting said cutting tool into strictly determined positions under impact of cutting resistant forces, the cutting tool nose movement has sinusoidal shape with different oscillation amplitude A and micro asperity height h, while said amplitude A and micro asperity height h have possibility to be regulated;
- at phase angle τ values equal to zero, π and 2π, cutting tool edges positions under angle oscillations coincide with those of even cutting, the cutting layer section and micro asperity height for indicated phase angle values are equal, while the cutting tool nose paths of two consecutive revolutions provide intermittent chips;
- at phase angle τ equal to π divided two times ($\pi/2$) the cutting tool nose paths are located on the maximum distance from each other, micro asperity height (h_{max}) is maximal, cutting tool nose oscillation amplitude fulfills condition A=0.5S, where S is feed value, thus intermittent chips are provided;
- at phase angle τ equal to three π divided two times ($3\pi/2$) the cutting tool nose paths touch each other, the cutting layer section is minimal, the cutting layer depth changes to zero and chips fracture occurs.

The machined workpiece 1 (Fig.1) is secured into lathe chuck 2. The proposed cutting tool 3 is secured into lathe tool holder 4.

Upon this the vibrating cutting tool 3 (Fig.2 to Fig.7) contains a fixed working part 5, a cover 6 connected to the said working part; an oscillation loop 7, comprising front movable working cutting tool part 8, one or several replaceable cutting plates 9 which are secured on the said movable working part 8; a set of elastic elements 10, 10* and 10** which connects said movable working cutting tool part with the basis of the said fixed cutting tool working part; said oscillation loop shaft 11 secured between said fixed working part basis and said cover; bearing assemblies 12 and 12* secured between said shaft and said fixed cutting tool part; upon this said movable cutting tool working part with secured on it said replaceable cutting plate is secured on the said shaft with possibility to be rotated due to cutting forces components appeared when performing machining process.

The vibration cutting method is performed as follows: The lathe chuck 2 power supply is switched on and machining workpiece1 which is secured in the lathe chuck 2 performs rotational movement with angle speed ω. The said vibrating cutting tool 3 which is secured into lathe cutting tool holder 4 is driven up to the moment when cutting tool 3 nose touches with rotating machined workpiece 1 surface. Then the said cutting tool 3 is removed from the machined workpiece 1 and a cutting depth t is adjusted. Then working feed S is adjusted for the said cutting tool. The cutting depth is formed as a result of two movements: machined workpiece 1 rotation movement with angle speed ω and feed movement S. The machined workpiece 1 angle speed $\omega(\tau)$ and cutting tool 3 linear speed which is equal to feed value are variable values. The law of the cutting tool 3 oscillatory movement is harmonic:

$$J_1=A_1\sin(\tau-\tau_0)$$

$$J2=A_2\sin\tau$$

Where J – cutting tool 3 turn angle referred to perpendicular raised from oscillation shaft K to machined workpiece 1 surface, for the first (1) and second (2) machined workpiece 1 revolutions accordingly;

A - angle oscillation amplitude

τ - phase shift angle

τ_0 - phase shift angle taking into account non integer number of oscillations per one revolution.

When cutting with angle oscillations (Fig.1) the cutting tool 3 performs, referred to machined workpiece 1, angle oscillations in XOY plate except movement in feed S direction. Fig.2 shows machined surface and cut layer sections after quarter of a period for phase angle shift $\tau_0=\pi$. The cutting tool 3 cutting edges positions (Fig.2) are marked: at the first revolution – main cutting edge G_1 and additional V_1, at second revolution G_2 and V_2 accordingly. Circumference length along machined worpiece 1 surface (Fig.3) is considerably more than cutting tool 3 feed per machined workpiece 1 revolution, i.e. π D >> S. Thus cutting tool nose paths on two consequent revolutions differ slightly from sinusoids with equal frequency and amplitude shifted from each other along X axis by feed value and along Y axis by phase angle τ_0. For cutting process interruption cutting tool 3 nose paths approach each other to the utmost at two consequent revolutions. Here condition is fulfilled: oscillation amplitude A necessarily is equal to feed value divided two times sinus of half τ_0

$$A=\frac{S}{2\sin\tau_0/2}$$

In considered case (Fig.2a) where $\tau_0=\pi$, oscillation amplitude A is half of feed A=0.5 S, this provides intermittent chips. Thus at $\tau=0, \pi, 2\pi$ (fig.2a) the cutting layer section P and micro asperity height are equal and coincide with even cutting positions.

At $\tau=\pi/2$ (Fig.2b) cutting tool nose paths are located on the maximum distance from each other and at this moment micro asperity height h is maximal and is defined by the formula: micro asperity height h is equal to feed S double value times sinus of difference between cutting edge position main angle φ and workpiece 2 and angle amplitude A_1 times sinus of difference between cutting edge position additional angle φ_1 referred to workpiece 2 and angle amplitude A_1 divided by sinus of the sum of the main and additional cutting edges position angles φ and φ_1 minus angle oscillation amplitude double value; to add value of the distance from the cutting edge nose to oscillation axis l_0 times difference between one and cosine of angle amplitude A_1 value

$$h_{max} = \frac{2S \sin(\varphi - A_1)\sin(\varphi - A_1)}{\sin(\varphi + \varphi_1 - 2A_1)} + l_0(1 - \cos A_1)$$

When $\tau = 3\pi/2$ (Fig.2c) the cutting tool nose paths touch or maximally approach each other. In this case the cutting layer section is minimal and it is defined according to the following formula: the minimal cutting layer section P_{min} is equal to the squared difference between cutting depth t and distance l_o from the cutting tool nose to oscillation axis times difference between one and cosine of the angle oscillation amplitude A_1 value times sinus of the angle oscillation amplitude A_1 double value divided by the double product of the sine of the sum of main cutting edge position angle φ and angle oscillation amplitude A_1 value and sine of the difference of main cutting edge position angle φ and angle oscillation amplitude A_1 value:

$$P_{min} = \frac{[t - l_o(1 - \cos A_1)]^2 * \sin 2A_1}{2\sin(\varphi + A_1)\sin(\varphi - A_1)}$$

It is seen from Fig.3 that P_{min} area is not equal to zero but for appropriate over design consideration distances l_o the P_{min} value is sufficiently small and practically provides chips fracture when machining any material.

For considered turning machining operation of the workpiece 1 with angle oscillations of the said cutting tool 3 the oscillation loop 7 of said cutting tool 3 performs function of pendulum with oscillation shaft K. When inertia moment I_{xoy} of the oscillation loop rectangular section movable part being equal to 0.0833 ml^2 kg/mm^2 a general turning rigidity C of the oscillation loop movable part is defined by formula:

$$C = \frac{(mlA\omega)^2}{2I}$$

where:

m - loop movable part mass, kg

l - loop movable part general length

ω - oscillation rotational frequency, Hz

I – oscillation loop movable part inertia moment.

Upon this the said rigidity C provides cutting tool 3 amplitude A within 0.2–0.5 mm limits which is sufficient for reliable fraction of machined workpiece 1 chips.

The elasticity force F is derived from the relation $F_y = C\,\lambda$ kg where:

λ - movement value equal to oscillation amplitude value A.

By adjusting elastic elements 10, 10*and 10** rigidity, a sufficient oscillation loop 7 movable part and the cutting tool 3 removable cutting part 9 oscillation amplitude A value is provided. Thus reliable and stable chips fraction is achieved when machining workpiece 1. Application of oscillation loop 7 without oscillation axis K enables to get practically various oscillation loop schemes:

- with axis oscillations of the movable part of the cutting part loop using elastic elements that provide linear movements only;

- with tool torsional oscillations, upon this for hole machining operation it is enough to install elastic element as torsion bar with torsion angle which provides reliable and stable chips fraction.

The use of cutting forces to perform oscillation loop vibrations of the proposed vibration cutting tool enables to completely exclude individual energy supply to the cutting tool and to exclude additional devices to perform cutting tool oscillations. The use of the proposed vibration cutting method when machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials enables to control quality performances of cutting process, machined surface micro asperity height thus providing high speed cutting with simultaneous stable and reliable chips fracture.

The presence of axis in the movable working forepart of the proposed cutting tool produces indispensable resistance forces for reduction oscillation amplitude of said cutting tool, i.e. provides automatic protection of cutting tool from overloads thus increasing its service life and makes all machining process more economically efficient.

Application of elastic elements in the proposed vibration cutting tool design enabled to increase cutting plate durability when machining above mentioned materials.

Those skilled in this art will easily find that various configurations and modifications are applicable to above mentioned examples of the invention realization without departing from its scope which is formulated in proposed claims and is defined by these claims.

CLAIMS

1. A vibration cutting method when machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials on a lathe with cutting tool that has forward feed movement path comprising the following stages:
- a workpiece rotation around rotation axis;
- a cutting tool adjustment into strictly determined positions on its forward path movement according to angle workpiece movements during cutting process so that under impact of cutting resistance forces the cutting tool nose position has sinusoidal shape with different oscillation amplitude and micro asperity height, while said cutting tool nose oscillation amplitude and said micro asperity height have possibility to be regulated and chips fracture is performed on the certain positions of phase angles;
- a regulation of the cutting tool nose oscillation amplitude by elastic elements of various rigidity, these elements are components of vibrating cutting tool oscillation loop.

2. A method according to claim 1 where:
- at phase angle $\tau = 0, \pi, 2\pi$ the cutting tool edges position at angle oscillations coincides with that of even cutting, the cutting layer section and micro asperity height are equal while the cutting tool nose paths on two consecutive revolutions provide intermittent chips,
- at phase angle $\tau = \pi/2$ cutting tool nose paths are located on the maximum distance from each other, micro asperity height h_{max} is maximal, while cutting tool nose oscillation amplitude fulfills condition $A=0.5S$ thus providing intermittent chips;
- at phase angle $\tau = 3/2\pi$ the cutting tool nose paths touch each other, the cutting layer section is minimal and so the cutting layer depth changes to zero and chips fracture occurs for various machined material.

3. A vibrating cutting tool for machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials comprising fixed working cutting tool part; a cover connected to the said fixed working part; an oscillation loop which includes movable working cutting tool part; one or several replaceable cutting plates, secured on the said movable working forepart; a set of elastic elements which connect said movable working cutting tool part with the basis of the said fixed working cutting tool part; an oscillation shaft of said oscillation loop, secured between said fixed cutting tool working part basis and said cover while said movable working part with secured on it said replaceable cutting plate is secured on said shaft with possibility of rotation due to cutting forces components, occurring during machining process.

AMENDED CLAIMS

[Received by the International Bureau on 25 AUG 2003 (25. 08.03) ; original claims 1 and 3, amended ; original claim 2, unchanged]

1. A vibration cutting method when machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials on a lathe with cutting tool that has forward feed movement path comprising the following stages:
   - a workpiece rotation around rotation axis;
   - a cutting tool adjustment into strictly determined positions on its forward path movement according to angle workpiece movements during cutting process so that under impact of cutting resistance forces the cutting tool nose position has sinusoidal shape with different oscillation amplitude and micro asperity height, while said cutting tool nose oscillation amplitude and said micro asperity height have possibility to be regulated and chips fracture is performed on the certain positions of phase angles;
   - a regulation of the cutting tool nose oscillation amplitude by elastic elements of various rigidity, these elements are components of vibrating cutting tool oscillation loop.

   whereby the oscillation loop is actuated solely by forces generated by dynamic engagement between the workpiece and the nose of the cutting tool.

2. A method according to claim 1 where:
   - at phase angle $\tau = 0, \pi, 2\pi$ the cutting tool edges position at angle oscillations coincides with that of even cutting, the cutting layer section and micro asperity height are equal while the cutting tool nose paths on two consecutive revolutions provide intermittent chips,
   - at phase angle $\tau = \pi/2$ cutting tool nose paths are located on the maximum distance from each other, micro asperity height h_{max} is maximal, while cutting tool nose oscillation amplitude fulfills condition A=0.5S thus providing intermittent chips;
   - at phase angle $\tau = 3/2\pi$ the cutting tool nose paths touch each other, the cutting layer section is minimal and so the cutting layer depth changes to zero and chips fracture occurs for various machined material.

3. A vibrating cutting tool for machining hardly machined steels, alloys, tenacious non-ferrous metals and composite materials comprising fixed working cutting tool part; a cover connected to the said fixed working part; an oscillation loop which includes movable working cutting tool part; one or several replaceable cutting plates, secured on the said movable working forepart; a set of elastic elements which connect said movable working cutting tool part with the basis of the said fixed working cutting tool part; an oscillation shaft of said oscillation loop, secured between said fixed cutting tool working part basis and said cover while said movable working part with secured on it said replaceable cutting plate is secured on said shaft with possibility of rotation due to cutting forces components, occurring during machining process, whereby the elastic elements of the oscillation loop are actuated solely by and regulated according to the forces generated by dynamic engagement due to cutting forces components occurring during the machining process.

STATEMENT UNDER ARTICLE 19(1) (Rule 46.6)

In the application of OREN Elimelech et al filed on 17 March 2003
for "METHOD AND APPARATUS FOR VIBRATING CUTTING TOOL"

The claims 1 and 3 have been amended and claim 2 unchanged. This amendments has been carried so as to definitely establish and clarify the advantage and the inventive step of the apparatus and method disclosed in the present invention in which the elastic elements of the oscillation loop are actuated by forces generated by dynamic engagement between the workpiece and the nose of the cutting tool. The oscillation movements are not produced by actuators of any type or kind as disclosed in cutting tools of the prior art.

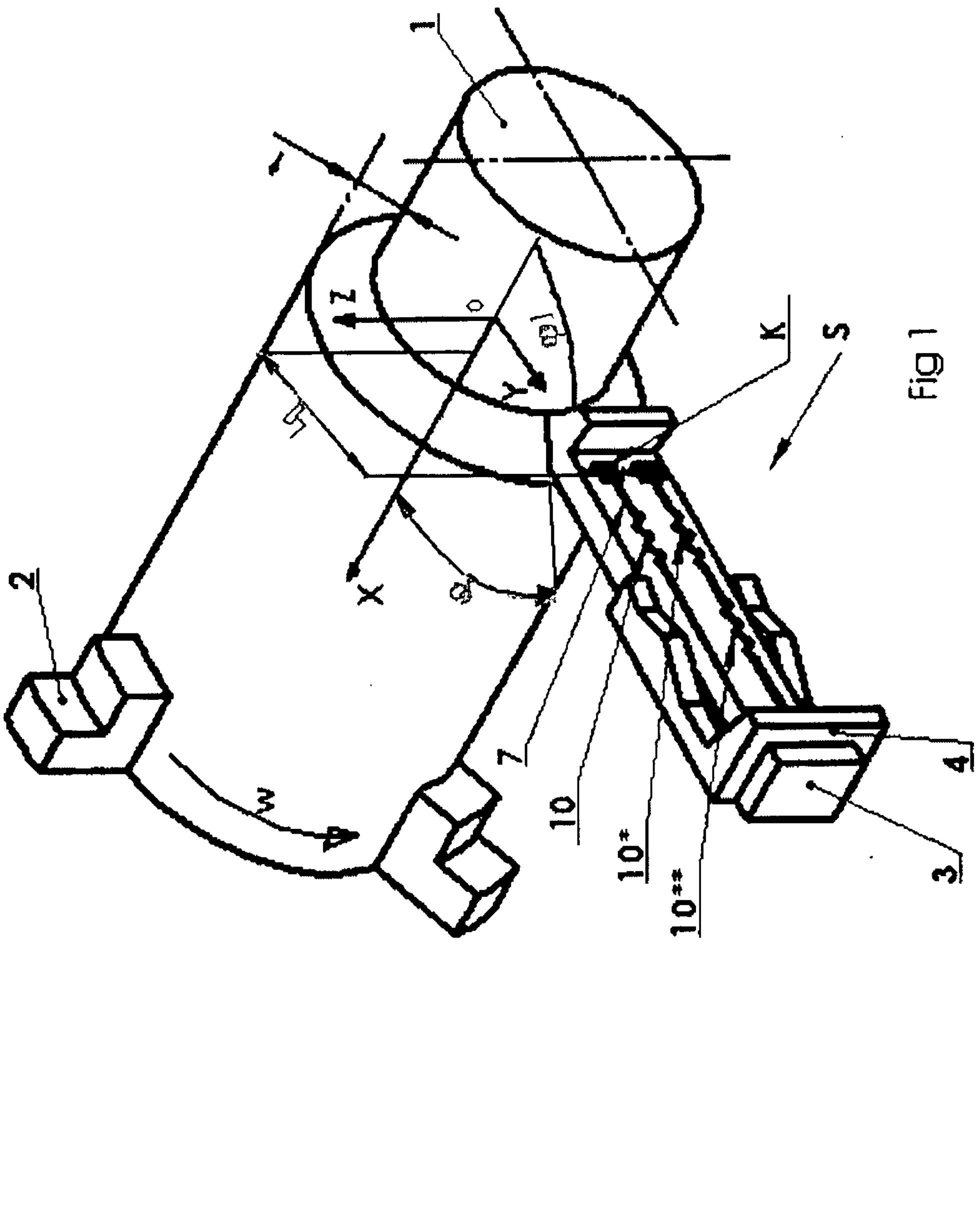
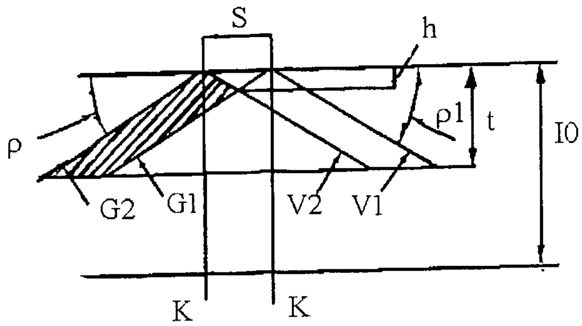


Fig 1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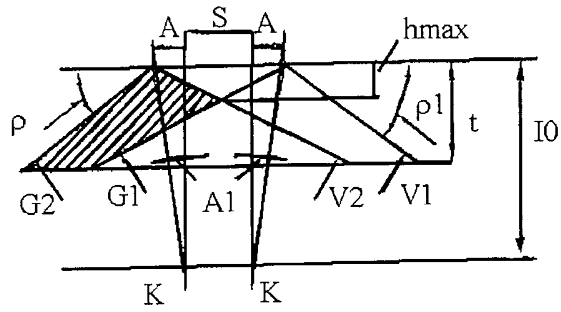
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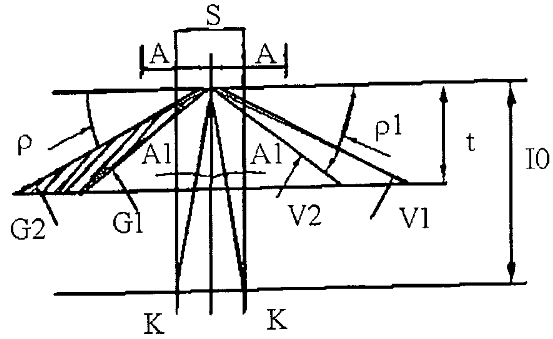
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Figure 2

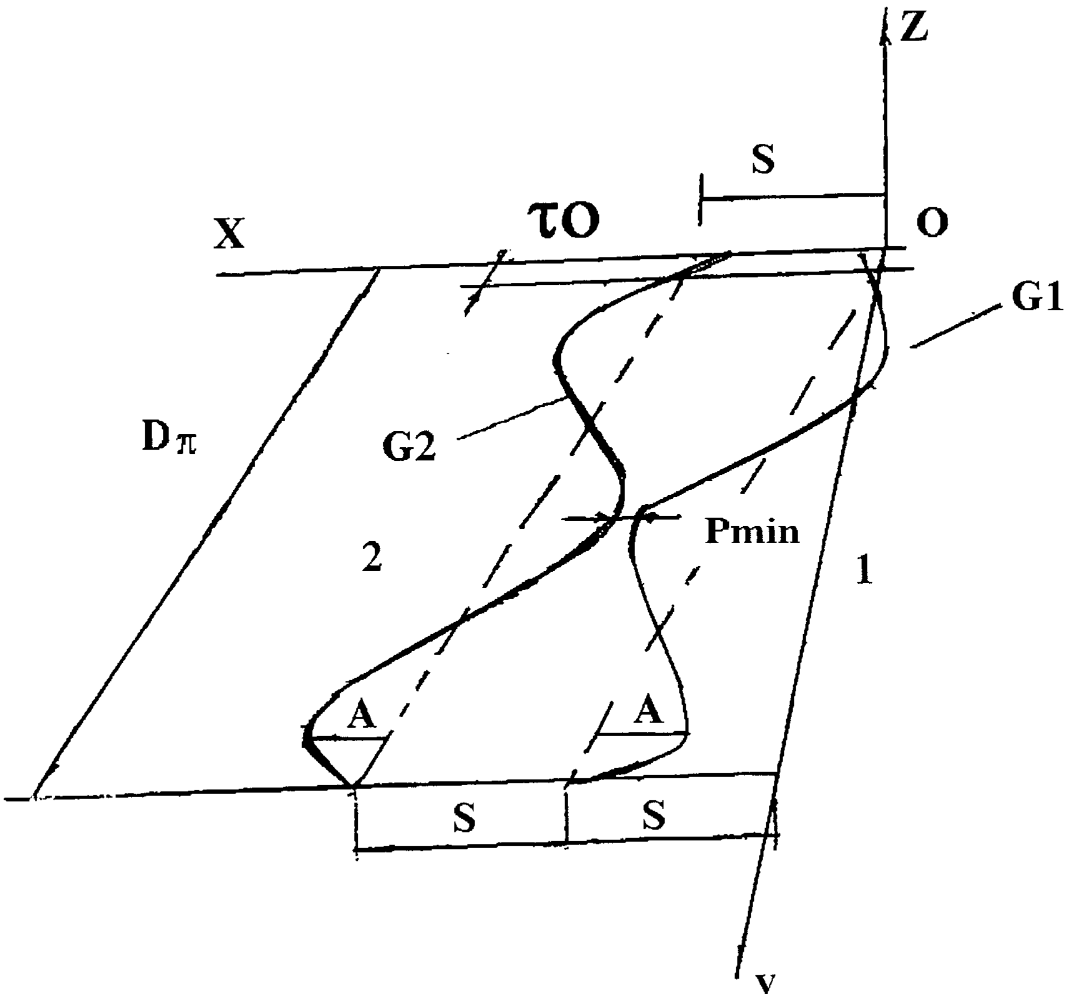

Figure 3

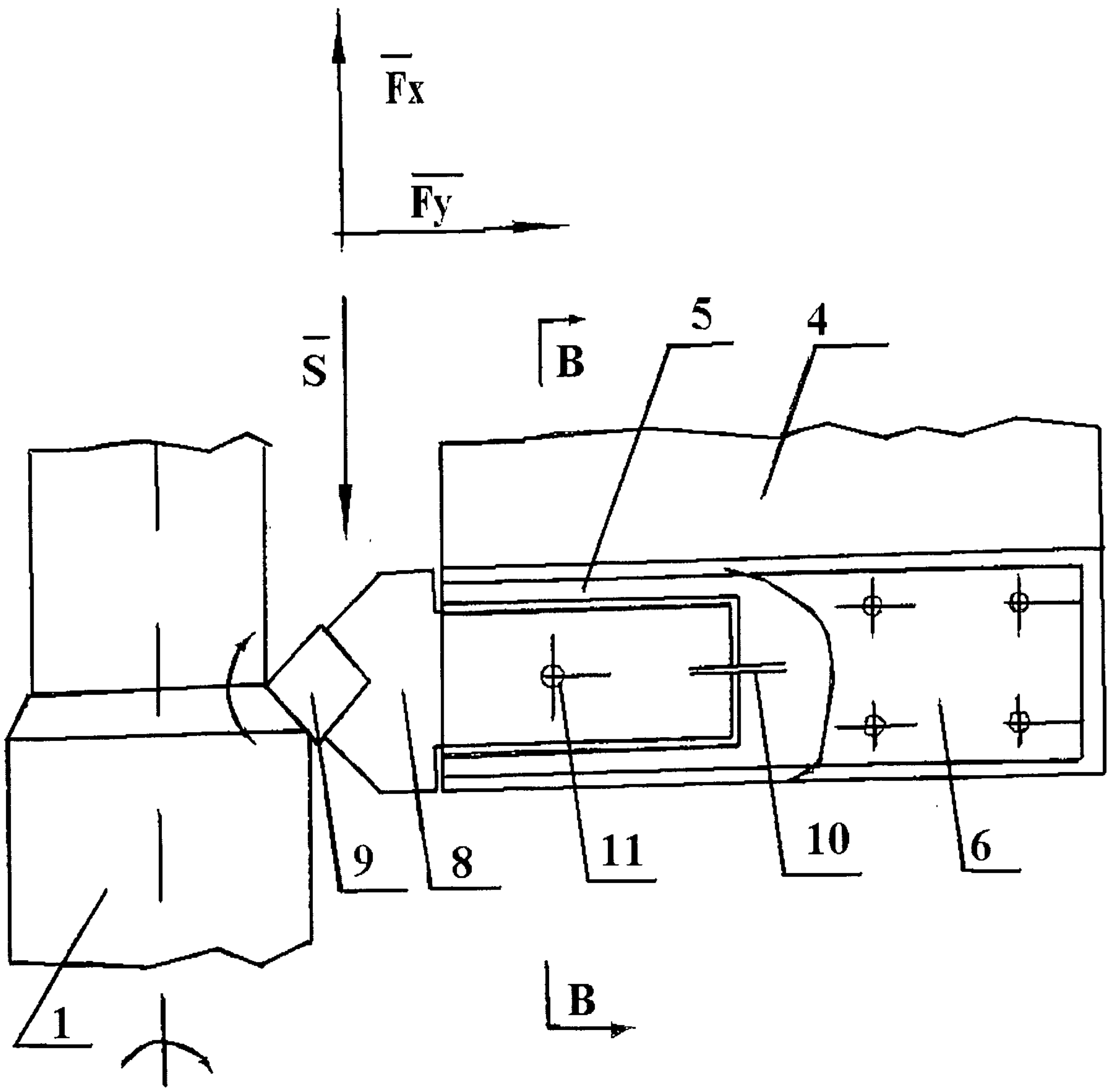

Figure 4

B - B

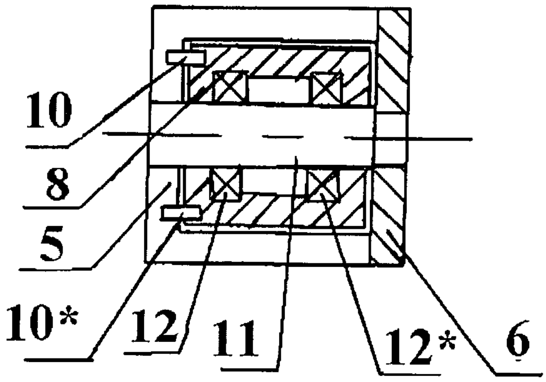

Figure 5

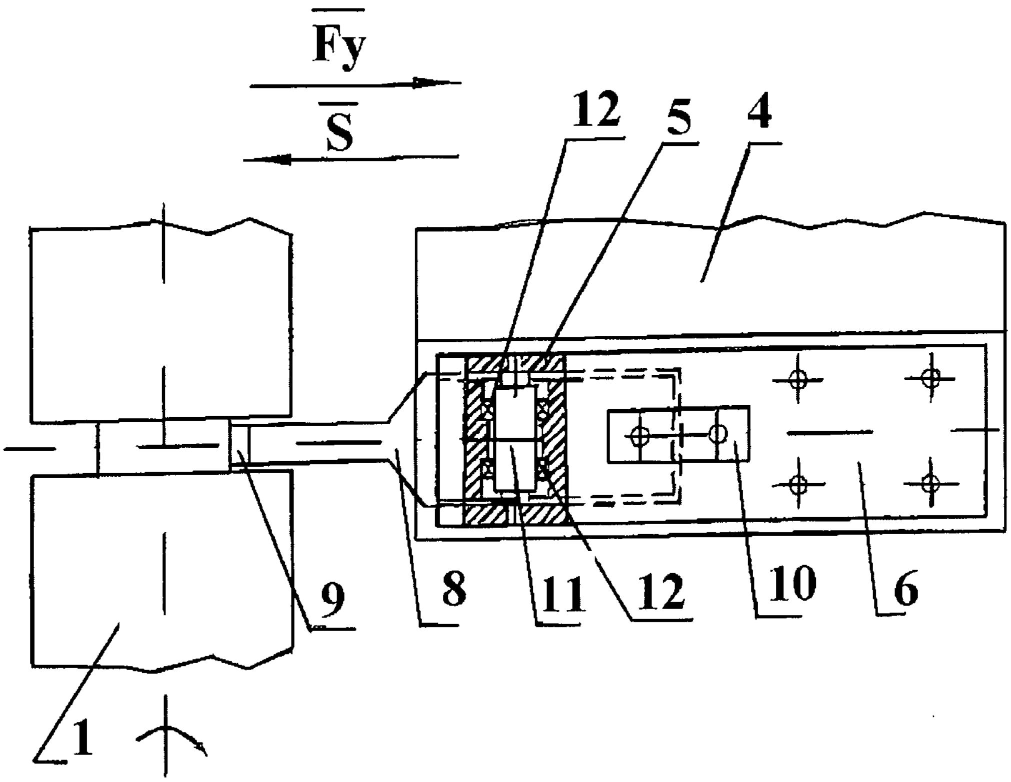

Figure 6

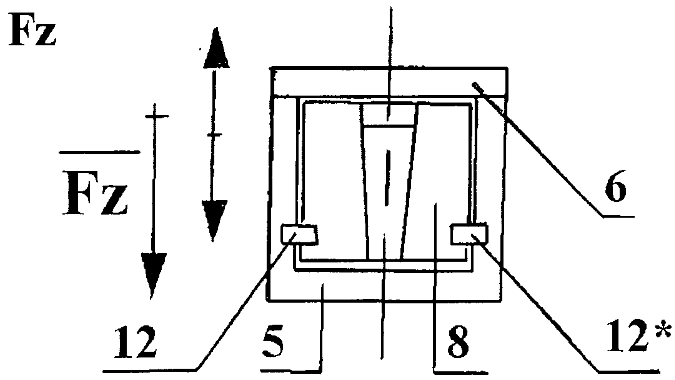

Figure 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL03/00232

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : B23B 3/00
US CL : 82/1.11

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 82/1.11, 158, 904; 407/1, 8, 9, 73

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,342,152 A (MEDEKSZA) 30 August 1994 (30.08.1994), See column 9, lines 53-63, column 7, lines 13 - 22.	1-3
Y	US 5,829,927 A (NAKAMURA et al) 03 November 1998 (03.11.1998), See column 18, lines 10 - 13.	1-3

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search
11 June 2003 (11.06.2003)

Date of mailing of the international search report
30 JUN 2003

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INTERNATIONAL SEARCH REPORT

PCT/IL03/00232

Continuation of Item 4 of the first sheet:
Title has been changed to comply with PCT Rule 4.3. The new title as:
METHOD AND APPARATUS FOR VIBRATING CUTTING TOOL